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EP 0299143 A **US 4818834 A**

(58) Field of Search
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(54) Abstract Title
Micromachining holes in a coated workpiece

(57) The invention provides a process and apparatus for the drilling of air holes in a workpiece to which a thermal barrier coating has been applied, comprising:

mounting on the same support platform of a machining tool a laser head and, at a predetermined offset from the laser head, an EDM head;

using the laser to ablate, under microprocessor control, the thermal barrier coating and any underlying bond coats over at least one site of an air hole to be drilled through a wall of the workpiece;

moving the support platform laterally by the amount of the predetermined offset; and

using the EDM head, under the same microprocessor control, to create the air hole through the wall of the workpiece beneath the or each surface-ablated site.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

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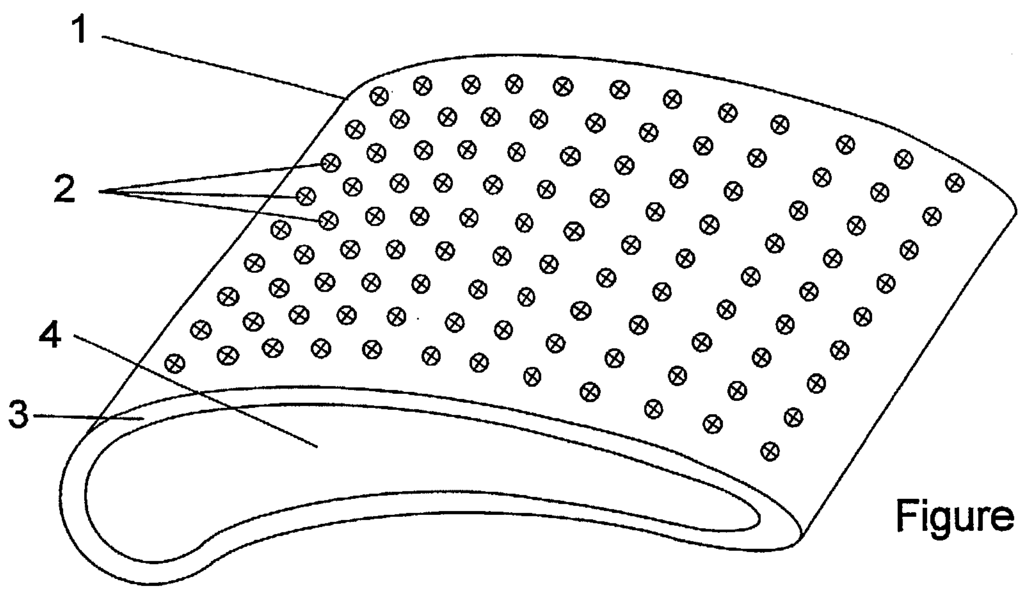

Figure 1

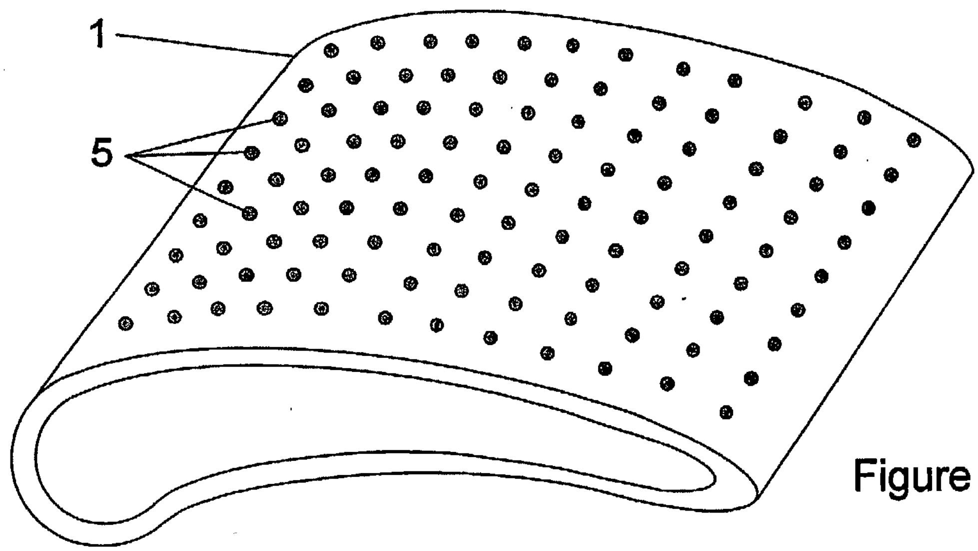

Figure 2

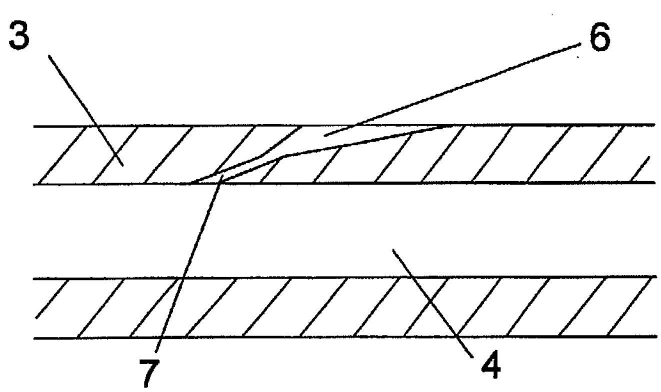

Figure 3

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TITLE

Micromachining holes in a coated workpiece

DESCRIPTION

Field of the Invention

The invention relates to the micromachining of holes in a workpiece such as a blade or vane of a gas turbine rotor or stator.

Background Art

Gas turbine engines such as aero engines have turbine blades and vanes made from high specification high melting alloys. However over much of the working life of the engines the turbine internal temperatures exceed the melting points of those alloys, so measures have to be taken to maintain the surface temperatures of the blades and vanes below the respective alloy melting temperatures. Generally air holes are formed through the surfaces of the blades or vanes exposed to the high temperatures, and cooling air is passed through those holes to form a film of heat insulating and cooling air between the high temperature gases in the turbine and the surfaces of the blades and vanes. The technology requires that the cooling air is developed as a continuous film over the whole of the exposed surfaces of the blades or vanes, and to achieve that the holes are generally designed to be of a predefined geometry, opening out in cross-section in the direction towards the exposed surface to be cooled. Such holes are commonly referred to as fan-shaped holes, because in section they have the shape of a fan at the exit side for the cooling air.

Several techniques have been developed for the machining of such fan-shaped holes for aero engine components. EDM (electrical discharge machining) was the first used machining technique, and this process is described in many pieces of prior art. The EDM machines have used round or shaped electrodes, but a general shortcoming of such a process has been the slow speed of machining the holes. The speed can be increased by using banks of electrodes fed from a single machining head, but that means that the shape and orientation of adjacent holes are generally identical, which may not give the optimum airflow pattern over the finished blade or vane.

Some blades or vanes have been coated with a thermal barrier coating, intended to provide some measure of thermal insulation to the metal from which the blade or vane is made. The thermal barrier coating is not intended to replace the need for a cooling film over the surface of the blade or vane in use, but does reduce the sensitivity of the blade material to thermal damage in use.

One consequence of using thermal barrier coatings on turbine components is that the coating creates an electrically insulating barrier over the surface of the blade or vane, so that the coated component cannot be machined using EDM methods, which require an electrically conductive path through the component. Therefore the most common method of drilling the air holes in thermal barrier coated blades and vanes has been the use of laser drilling. Laser drilling is faster than EDM drilling, but a high power laser creates holes which are of generally lower quality and have a lower surface accuracy because such a laser can create problems such as recast metal deposition and metallurgical cracking problems.

It has been proposed to avoid the above problems by drilling the component first, and then applying the thermal barrier coating subsequently. The EDM technique can be used for the drilling, because it is carried out before the electrically insulating thermal barrier coating is applied. Even that technique has its disadvantages, however, as the application of the thermal barrier coating can cause problems of restriction of the hole size or even complete hole blockage. Another technique that has been proposed therefore is to secure the thermal barrier coated workpiece on a worktable of a laser drilling machine and to surface-ablate the entire pattern of sites for the air holes; then to move the workpiece to an EDM machine which has a sensor or probe mounted on the drilling head adjacent to the EDM wire electrode. The probe is used to sense the position of each surface-ablated site prior to the EDM machining of the hole at that site. Once the position of the surface-ablated site is established, the EDM drilling can take place normally because the laser has removed the electrically insulating coating from the surface of the workpiece in the location of the hole site. The probe measurement must, however, be used to find each individual hole site in turn before EDM drilling can take place at that site. The

speed of the process is therefore much slower than even the EDM drilling of holes in an uncoated workpiece, and the process is therefore more expensive.

It is an object of the invention to avoid the above problems and to provide a novel method of creating accurately drilled holes in a thermal barrier coated workpiece, in an economically rapid process.

<u>The invention</u>

The invention provides a process for the drilling of air holes in a workpiece to which a thermal barrier coating has been applied, comprising:

mounting on the same support platform of a machining tool a laser head and, at a predetermined offset from the laser head, an EDM head;

using the laser to ablate, under microprocessor control, the thermal barrier coating and any underlying bond coats over at least one site of an air hole to be drilled through a wall of the workpiece, optionally together with a portion of the workpiece base material beneath the thermal barrier coating at that site;

moving the support platform laterally by the amount of the predetermined offset; and

using the EDM head, under the same microprocessor control, to create the air hole through the wall of the workpiece beneath the or each surface-ablated site.

It is not necessary to change from the use of the laser to the use of the EDM head on a single hole-by-hole basis. A number of sites may be surface-ablated using the laser before the process moves the support platform laterally by the amount of the offset and changes over to EDM mode. Indeed it is generally preferable to surface-ablate the entire sequence of hole sites in the workpiece before changing over to the EDM mode.

The process of the invention is very flexible, and permits the creation of shaped air holes such as the fan-shaped holes described above. The laser may ablate not only the thermal barrier coating but also the base material of the component under the site of the hole to be formed, to create the shape of the fan-shaped part of the hole. In this cavity-forming mode the laser beam preferably moves in a predetermined pattern in order best to remove the debris from the cavity being formed.

Laser machining heads and EDM heads operate under substantially different operating environments, and it is surprising that the use of the two different machining heads can be contemplated on a single machine tool support platform. A YAG laser, for example, operates in dry conditions at an operating temperature of typically about 38°C. On the other hand an EDM head operates at about 4°C to 6°C and in the presence of a constant spray of electrolyte. It is therefore necessary to isolate the two working heads of the combined machine, but it has been found that this can be achieved very simply and satisfactorily by housing the laser head in a water-resistant housing fitted with a splashproof door or shutter which closes across the path of the laser beam and effectively isolates the laser nozzle from the splashing electrolyte when the machine is in EDM mode.

The hardware requirements of the process of the invention, in addition to the above water-tight housing, are a machine tool platform and workpiece holding system with at least a five axis control of movement. For example the component may be held by a tilt and turn (A & B axis) rotary manipulator mounted on a moving X & Y axis platform, with the machine tool platform being movable along the Z axis and optionally about the C axis. Alternatively the component may be held by a single rotary manipulator (C axis) mounted on a moving X & Y axis platform, with the machine tool platform being movable along the Z axis with B axis and optionally A axis rotation. Or the component may be held by a tilt and turn (B & C axis) rotary manipulator mounted on a moving Z axis platform, with the machine tool platform being movable along the X & Y axes and optionally about the A axis.

A CNC controller under microprocessor control is generally required to provide simultaneous 5-axis movement to perform the necessary ablation and drilling.

The laser would typically be a movable beam pulsed YAG based laser preferably operating in the infra-red or near-infra-red range, for example being one with laser light being generated in the 1064 wavelength. The laser is preferably a high repetition rate short pulsed laser. Examples of suitable lasers are Q-switched and mode locking lasers.

The beam movement of the above laser preferably comprises a 2-axis (X, Y) or 3-axis (X, Y, Z) means of deflecting the beam using, for example, controllable mirrors for the X, Y deflection and a controllable telescope controlling the depth of focus for the Z deflection. Such X, Y or X, Y, Z movement control is obtained by a device commonly called a galvanometer in the United Kingdom or a scanner in the USA. An alternative to optical movement of the laser beam might be to move the machine tool platform, but for most applications this would be considered too slow to be commercially useful in comparison with the much more rapid movement control available by optical means.

The EDM head would typically be one with a static or rotating single point electrode made from either brass or tungsten. Preferably the EDM head would use hollow tubular electrodes and would use deionised water as the dielectric, although solid electrodes and oil dielectric would be feasible but commercially inferior alternatives.

The software requirements are generally the ability to generate partial programmes for the laser control and the EDM control. The laser control would generally take the form of a CAD simulation of the exact geometry required for the location and angles of the individual holes advantageously overlaid with expulsion strategies for the efficient removal of debris during the ablation. The EDM control would generally take the form of a CAD simulation of the final finished shape, from which axis movements could be defined and post processed to create partial programmes which at the very least would contain axis movements for a particular machine type.

The partial programmes generated would depend on the cooling hole types to be created in the workpiece. For simple round holes for example, the laser head would be used to ablate the non-conductive coating from over the place that the hole is to be drilled. Then the coating and a small depth of the metal of the workpiece at the site of drilling would be ablated away, the small depth of metal being sufficient to ensure that the coating and any bond coats securing the non-conductive coating to the workpiece are completely removed. Finally the hole is drilled using EDM.

For fan-shaped cooling holes, the partial programs are rather more complex. Two strategies are possible, the preferred strategy depending on the specific geometry

and position of the hole. In a first strategy, the laser head is used to ablate the non-conductive coating from the surface where the hole is to be drilled, including the entire circumference of the diffuser or fan shape of the hole to be drilled. Laser ablation would then follow, using a predefined laser beam movement pattern until the entire fan-shaped cavity but not the through-hole into the plenum chamber have been drilled. Then the hole would be drilled using EDM.

In a second strategy, the laser head is used to ablate the non-conductive coating from the surface where the hole is to be drilled, including the entire circumference of the diffuser or fan shape of the hole to be drilled, but not including the fan-shaped cavity or not including all of the fan-shaped cavity. EDM machining would then follow, using a predefined movement pattern for the EDM head until the entire fan-shaped cavity but not the through-hole into the plenum chamber have been drilled. Finally the hole would be drilled using EDM. If desired the sequence of the above two EDM steps could be reversed.

The invention also provides an apparatus for carrying out the above process.

<u>Drawings</u>

Figure 1 is a perspective view of a turbine blade, shown schematically, with the predetermined sites of an array of air holes shown in the Figure;

Figure 2 is a perspective view of the same turbine blade with the sites surface-ablated to remove the thermal barrier coating over the surface of the blade at those sites only; and

Figure 3 is a section through the two walls of the turbine blade showing one hole that has been drilled and shaped by the process of the invention.

The component to be drilled with an array of air holes is shown in Figure 1 which shows schematically a turbine blade 1 for a gas turbine. The blade 1 is coated with a surface layer of a thermal barrier coating over a part of the blade surface or even over the entire blade surface. In Figure 1 a predetermined array of sites 2 is shown for the drilling of air holes through a wall 3 of the blade 1. In use, the top surface of the blade as viewed in Figure 1 is the high temperature side which is in contact with the hot turbine gases, and that surface is cooled and insulated from the heat by a

film of air generated over the entire surface by cooling air which passes out under pressure from an internal plenum chamber 4 of the blade. The fan shapes of the holes (see Figure 3) helps to create a uniform thin film of cooling air passing over the surface of the blade and protecting it from the hot exhaust gases of the turbine. The thermal protection of the blade 1 is however greatly assisted by the provision of the thermal barrier coating over the surface of the blade.

It will be understood that initially the blade 1 has a uniform surface coated with the thermal barrier coating, and the sites 2 shown in Figure 1 exist only in the microprocessor program and are not visible on the surface of the blade. Figure 2 however shows the blade at the end of the first surface-ablation step of the process of the invention. Ablated cavities 5 have been machined into the surface of the blade 1 using a pulsed YAG laser, the cavities 5 falling exactly over the sites 2 marked in Figure 1. The cavities 5 are surface recesses ablated completely through the thermal barrier coating and any underlying bond coatings over the surface of the blade, and expose the electrically conductive base material of the blade beneath them. Preferably the laser ablation is continued to create the shape of the generally fan-shaped recess or cavity 6 which is to be created in each through-hole as shown in Figure 3. Alternatively the shaping of the fan-shaped recesses 6 may be reserved until the final EDM step so as to create an accurately finished recess 6 without an excessive liability for surface cracking in the vicinity of the machined recess. First the laser burns through and ablates the thermal barrier coating. Then the EDM head shapes the fan-shaped cavity 6 and drills the through-hole 7 as shown in Figure 3. All that is needed is a sideways movement of the platform carrying the laser and EDM heads, by the exact amount of the linear offset between the laser and EDM heads on the same machine platform, and an effective shrouding of the laser head to protect it from electrolyte splashes when the EDM head is in operation.

The drilling is rapid and accurate. The rapidity is obtained from the fact that it is possible to use the laser head to ablate the thermal barrier coating and any underlying bond coats, and from the fact that the blade does not have to be taken out of the workpiece holder between the surface-ablation using the laser and the EDM processing. The accuracy is obtained from the fact that the same

microprocessor is used to access the same sites for both the laser control and the EDM control. The fact that the blade does not have to be taken out of the workpiece holder between the surface-ablation using the laser and the EDM processing adds to the accuracy as well as the rapidity of the process: the hole sites are accurately visited by both the laser head and the EDM head because the workpiece is not removed between the two steps.

CLAIMS

1. A process for the drilling of air holes in a workpiece to which a thermal barrier coating has been applied, comprising:

mounting on the same support platform of a machining tool a laser head and, at a predetermined offset from the laser head, an EDM head;

using the laser to ablate, under microprocessor control, the thermal barrier coating and any underlying bond coats over at least one site of an air hole to be drilled through a wall of the workpiece;

moving the support platform laterally by the amount of the predetermined offset; and

using the EDM head, under the same microprocessor control, to create the air hole through the wall of the workpiece beneath the or each surface-ablated site.

2. A process according to claim 1, wherein a number of sites are surface-ablated using the laser before the process moves the support platform laterally by the amount of the offset and changes over to EDM mode.

3. A process according to claim 2, wherein the laser head is used to surface-ablate the entire sequence of hole sites in the workpiece before changing over to the EDM mode.

4. A process according to any preceding claim, wherein the laser head is housed in a water-resistant housing in the machining tool, with a splashproof door or shutter which closes across the path of the laser beam and effectively isolates the laser nozzle from the splashing electrolyte when the machine is in EDM mode.

5. A process according to any preceding claim, wherein the workpiece is a blade or vane of a gas turbine engine; each air hole is a fan-shaped hole opening out in cross-section into a generally fan-shaped surface cavity at the hot temperature side of the blade or vane to spread the cooling air into a generally uniform film over the surface of the blade or vane to cool the blade or vane material and to provide thermal insulation from the hot combustion and exhaust gases in the gas turbine engine; the laser is used both to surface-ablate the thermal barrier

coating which covers the blade or vane base material at the site of each hole to be drilled and to remove by ablation the fan-shaped surface cavity being formed in the base material of the blade or vane; and the EDM head is used to drill the through-hole in the wall of the blade or vane.

6. A process according to any of claims 1 to 4, wherein the workpiece is a blade or vane of a gas turbine engine; each air hole is a fan-shaped hole opening out in cross-section into a generally fan-shaped surface cavity at the hot temperature side of the blade or vane to spread the cooling air into a generally uniform film over the surface of the blade or vane to cool the blade or vane material and to provide thermal insulation from the hot combustion and exhaust gases in the gas turbine engine; the laser is used both to surface-ablate the thermal barrier coating which covers the blade or vane base material at the site of each hole to be drilled; and the EDM head is used both to remove by EDM machining the fan-shaped surface cavity being formed in the base material of the blade or vane and to drill the through-hole in the wall of the blade or vane.

7. A process according to any preceding claim, wherein the laser is a pulsed YAG laser.

8. A process according to claim 7, wherein the laser is a Q-switch laser or a mode-locking laser.

9. A process according to any preceding claim, wherein the EDM head comprises a static or rotating single point electrode.

10. A process according to claim 9, wherein the or each EDM electrode is made of brass or tungsten.

11. A process according to any preceding claim, wherein the or each EDM electrode is a hollow tubular electrode and the dielectric is deionised water.

12. A process for the drilling of air holes in a workpiece to which a thermal barrier coating has been applied, substantially as described herein with reference to the drawings.

13. Aparatus for the drilling of air holes in a workpiece to which a thermal barrier coating has been applied, comprising:

a machine tool platform mounting a laser head and, at a predetermined offset from the laser haead, an EDM head;

a water-resistant housing around the laser head, including a splash-proof door or shutter across the path of the laser beam which effectively isolates the laser nozzle from any splashing electrolyte when the machine is in EDM mode; and

a microprocessor control unit which moves the machine platform in a pattern of movement to present the laser head to the workpiece at sites at which the air holes are to be drilled and which controls the laser to ablate the thermal barrier coating from those sites; and then subsequently to present the EDM head to the workpiece at the same sites to carry out EDM micromachining of the workpiece to create the air holes in the workpiece.

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Application No:	GB 0303024.4	**Examiner:**	A.R.Martin
Claims searched:	All claims	**Date of search:**	25 June 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1 and 13 at least	EP 0299143 A Raycon see col 4 line 50-col 5 line 25
Y	"	US 4818834 A Raycon see col 3 line 35-col 4 line 10

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

B3V

Worldwide search of patent documents classified in the following areas of the IPC^{7} :

B23H , B23K

The following online and other databases have been used in the preparation of this search report :

On line databases WPI,EPODOC,JAPIO